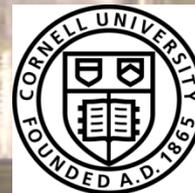
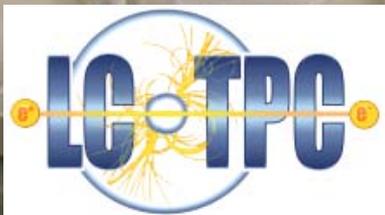


A TPC for the ILD detector: Status of the Endplate Design

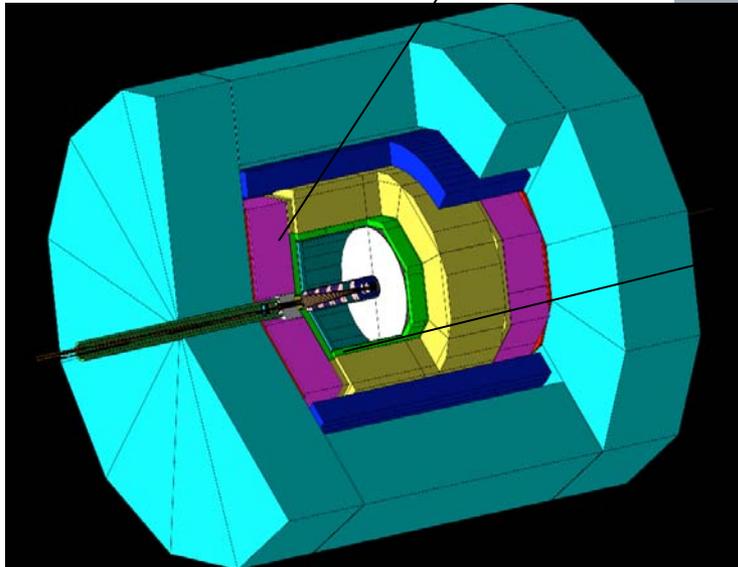
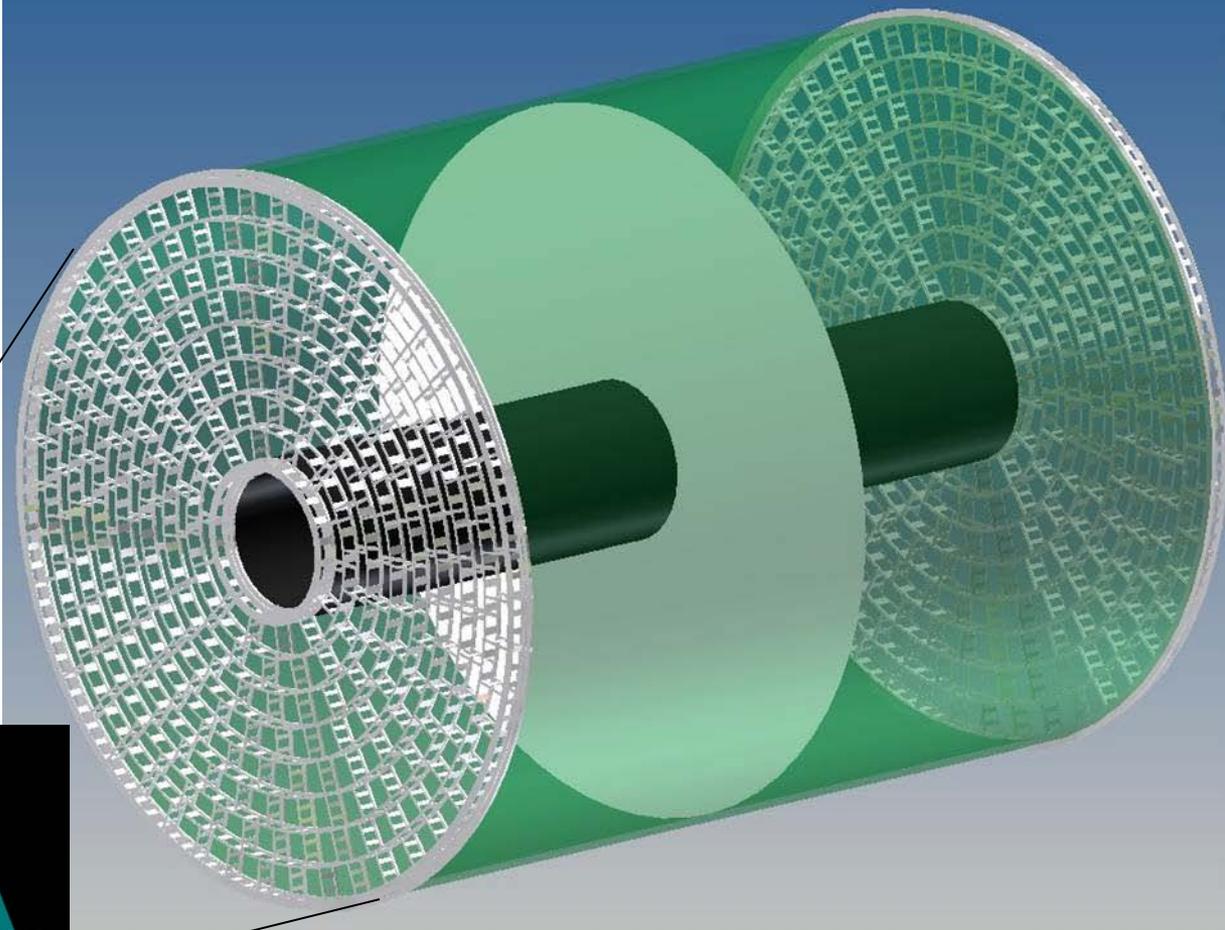
Dan Peterson

Laboratory for Elementary-Particle Physics, Cornell University



The TPC is the central tracker
for the ILD

with
outer radius 1808 mm
inner radius 329 mm
half length 2350 mm

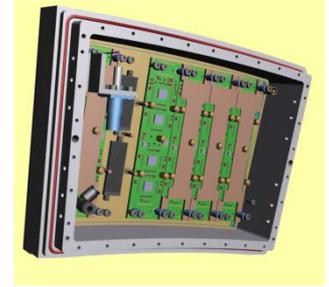


This is a report on the proposal for the
mechanical endplate of the ILD TPC
and
the studies leading to this proposal.

Goals of the ILD TPC endplate

Detector module design:

- Endplate must be designed to implement Micro Pattern Gas Detector (MPGD) readout modules.
- Modules must provide near-full coverage of the endplate.
- Modules must be replaceable without removing the endplate.



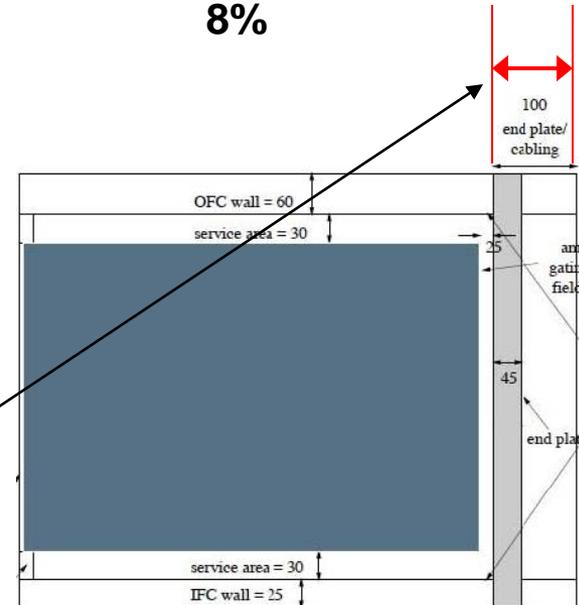
Low material - limit is set by ILD endcap calorimetry and PFA:

25% X_0 including	readout plane, front-end-electronics, gate cooling	5%
	power cables	2%
	mechanical structure	10%
		8%

Rigid - limit is set to facilitate the de-coupled alignment of magnetic field and module positions.

Precision and stability of x,y positions **< 50 μ m**

Thin - ILD will give us **100mm** of longitudinal space between the gas volume and the endcap calorimeter.



In 2008, Cornell constructed two endplates for the LCTPC Large Prototype (LP1). These were shipped August 2008 and February 2010, and are currently in use.



Inside the chamber



Outside the chamber

The endplate construction was developed to provide the precision required for ILD; precision features are **accurate to $\sim 30 \mu\text{m}$** .

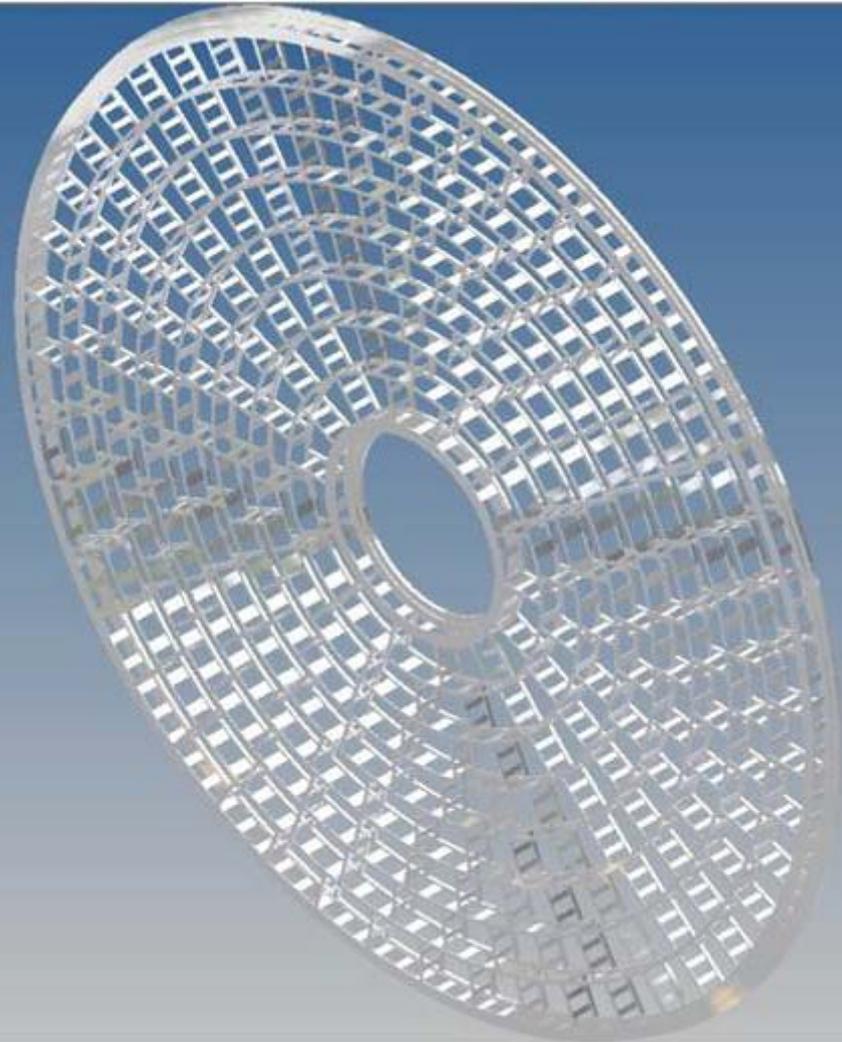
The accuracy was achieved with a 5-step process developed at Cornell, with 3 machining steps and 2 stress relief (cold shock) steps.

The LP1 endplate did not have a goal to meet the material limit; the bare endplate has mass 18.87 kg over an area of 4657 cm^2 ,
(mass/area) / (aluminum radiation length (24.0 g/cm^2)) = **16.9% X_0** , 2x goal.



back-frames, after liquid N₂ immersion

The **ILD endplate design** is a space-frame and shown here as the **solid model** used for the Finite-Element-Analysis (FEA).



(inside view)

This model has a full thickness of 100mm, radius 1.8m, and mass 136 kg.
The material thickness is then 1.34g/cm^2 , **6% X_0** .

A construction design is part of this study.

FEA calculations of deflection and stress (stress is not shown)

Endplate deflections were calculated with finite element analysis (FEA).

Endplate Support:
outer and inner field cages

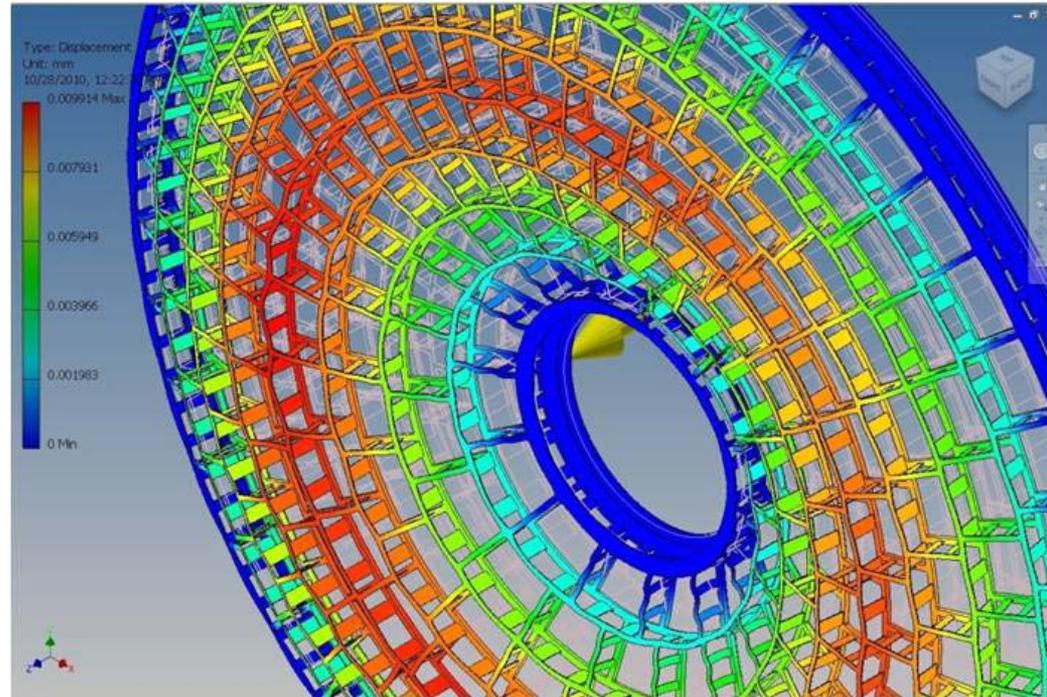
Maximum deflection
0.00991 mm/100N

Calibration: 100N is the force on LP1
due to 2.1 millibar overpressure
ratio of areas: (area of ILD)/(area of LP1) =21.9

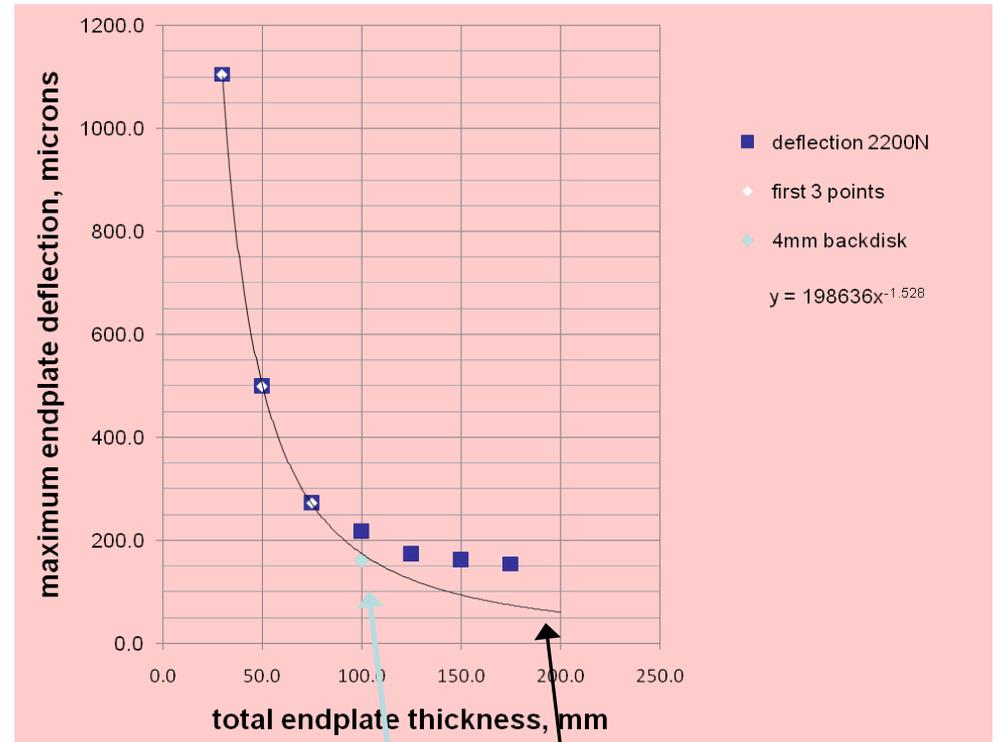
**deflection for 2.1 millibar overpressure
on the ILD TPC endplate (2200N)
= 0.22 mm**

Without the space-frame structure,
the simple endplate deflects by 50mm.

*Much of the remaining part of this study is to validate that
this calculation is accurate for the complicated structure.*



rigidity vs thickness



It was initially expected that the strength could be improved by asking ILD for more longitudinal space.

However, the improvement with thickness diminishes (deviates from power law) above 100mm. The deflection decreases from 220 microns to 160 microns with a 200mm total thickness.

The cause for the deviation from power law is small buckling, (most visible in inner layer).

Thus, the same improvement in deflection can be found with a modest increase in the back-plate thickness.

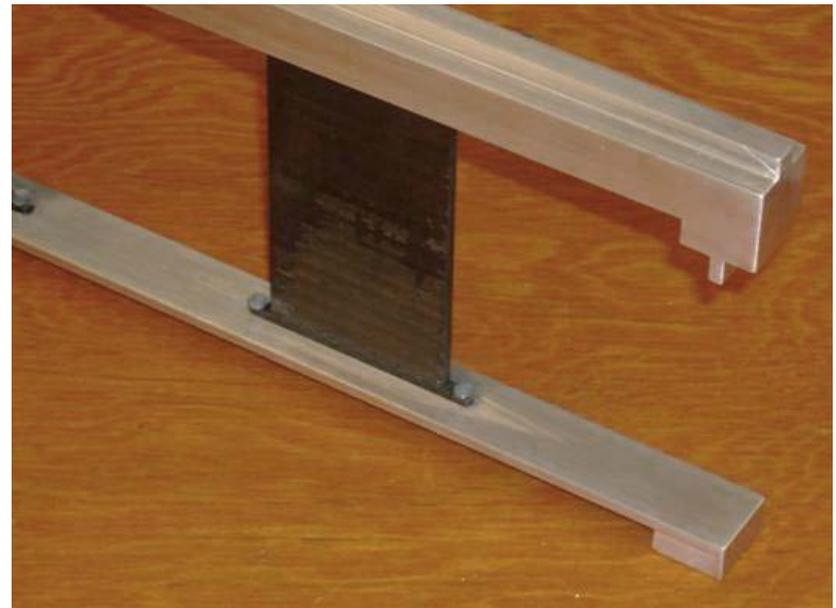
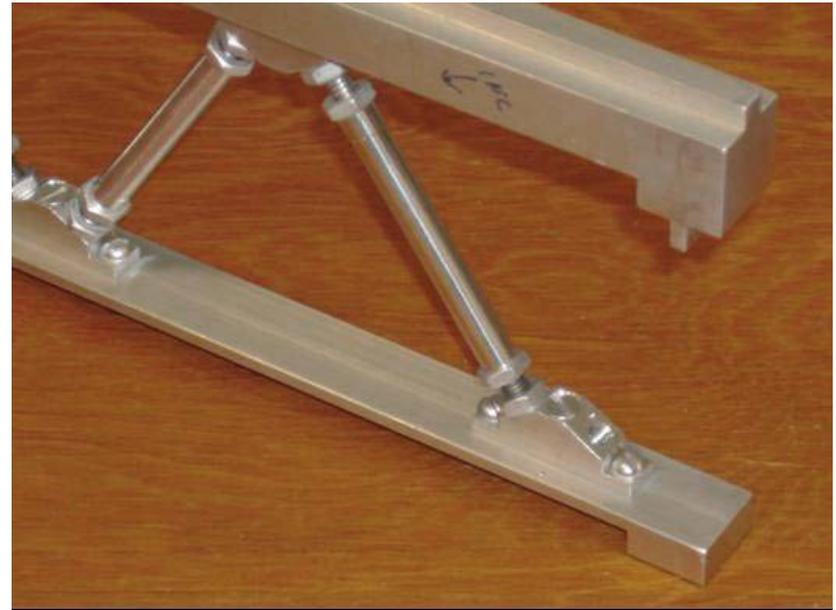
The ILD endplate **solid model** (previous slide) is modeled in the “equivalent-plate” space-frame design; the separating members are thin plates.

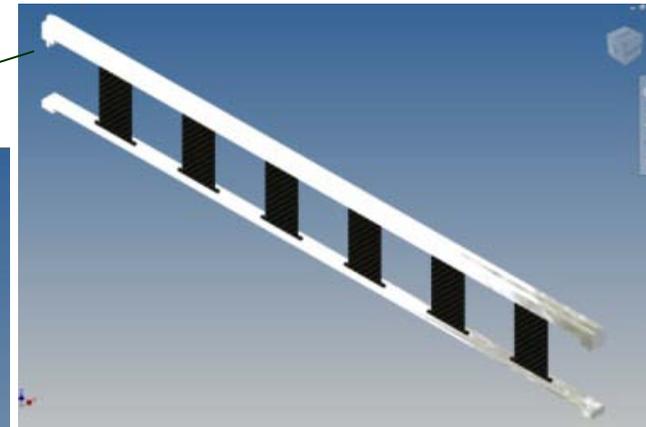
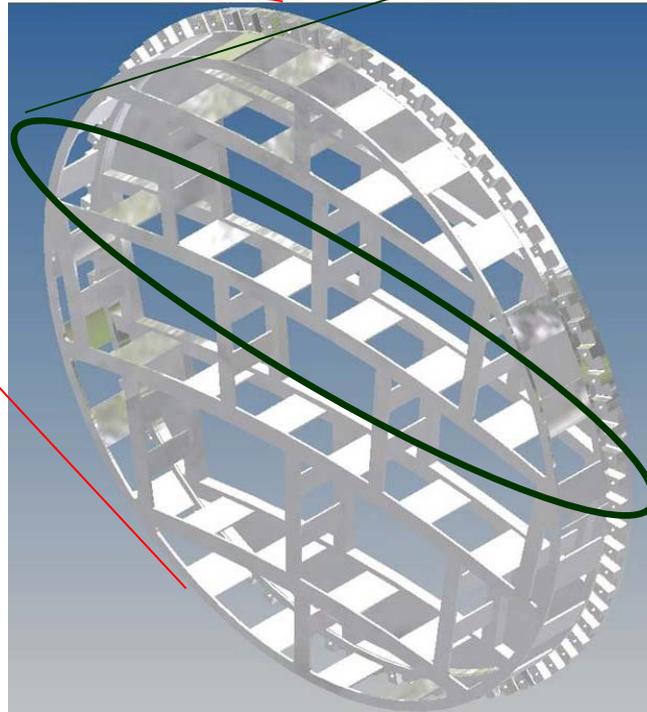
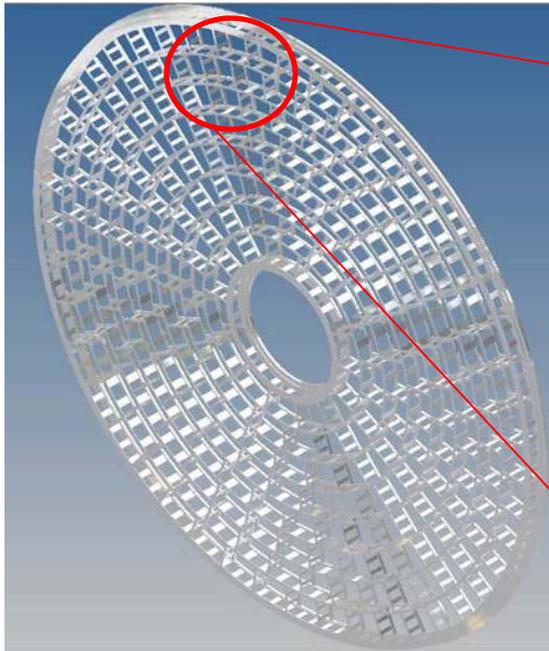
Shown at right are two **construction designs** for the space-frame:
“strut” and “equivalent plate”.

The thin plate **thickness and width** are adjusted to achieve **rigidity and material equivalent** to a strut design.

The final implementation of the ILD endplate may be either the strut or thin plate designs.

The ILD was modeled with equivalent plates only because the struts were too complicated for the FEA. Proving the equivalence is a part of this study.



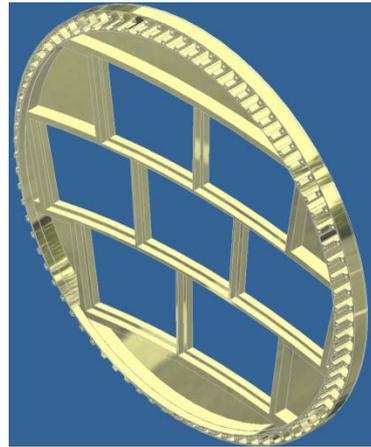


The ILD endplate design study involves endplates at 3 levels of scale.
The **LP1 and LP2 endplates** represent small sub-sections of an ILD endplate.
Small test beams represent a slice through the LP1 or LP2 endplates.

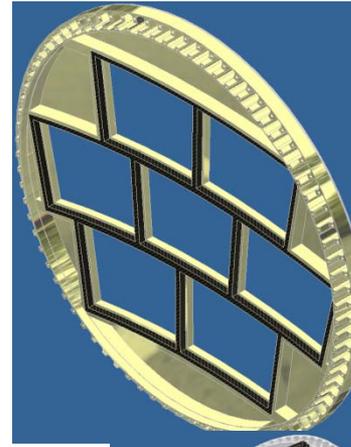
The measured performance, compared to FEA calculations, of the small test beams and LP1 and LP2 endplates, provide validation of calculations for the ILD endplate.



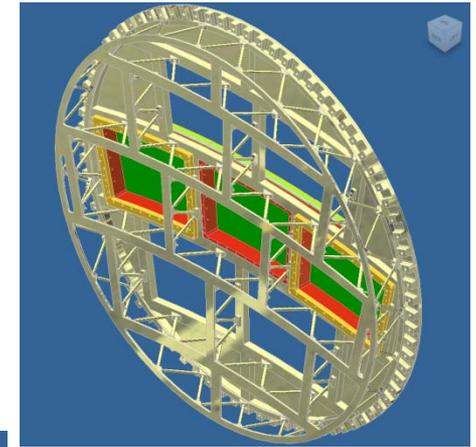
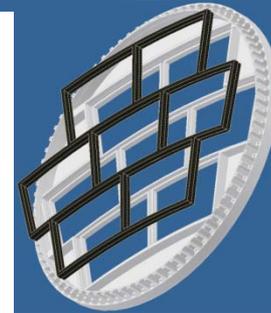
LP1 endplate,
thick aluminum



lightened, all aluminum



aluminum/
carbon fiber
hybrid



space frame

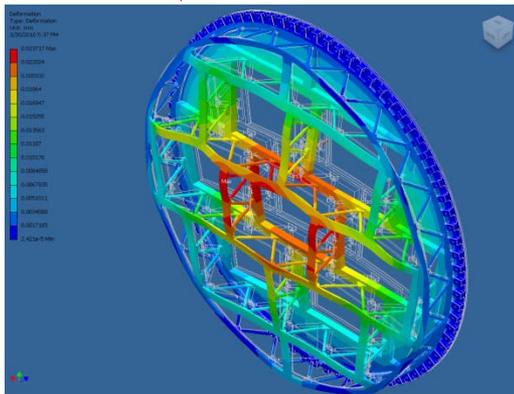
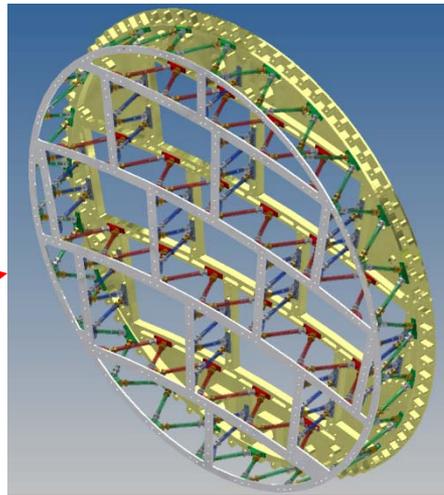
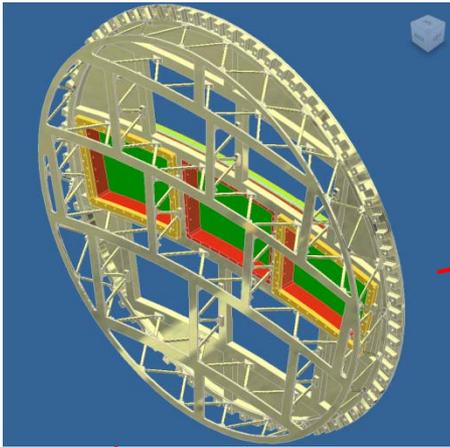
Various technologies have been considered.

The LP1 endplate is high material all aluminum.

Contributions to the strength of material in various locations were studied in lightened models.

A low material hybrid construction was an effort to provide the strength of the LP1 design, with significantly reduced material.

But, the space-frame promises to provide the greatest strength-to-material.



The study involves different purpose models as well as constructed prototypes.

Each technology (solid plate, spaceframe) in each scale (ILD, LP1/LP2, small test beam) starts as a solid model.

The solid model is used for the finite element analysis (FEA) and as a starting point for the construction model. (Solid and construction models share a common data base.)

The construction model defines the files to drive the machining for the physical prototype.

Measurements of the prototype are compared to the FEA.

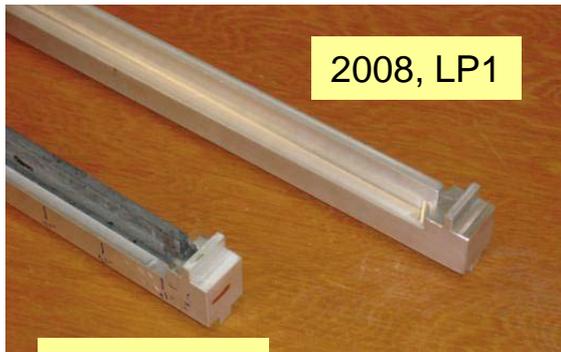
Validation of the FEA with small test beams

The small test beams represent sections of the LP1 endplate across the diameter of the LP1/LP2 endplate.

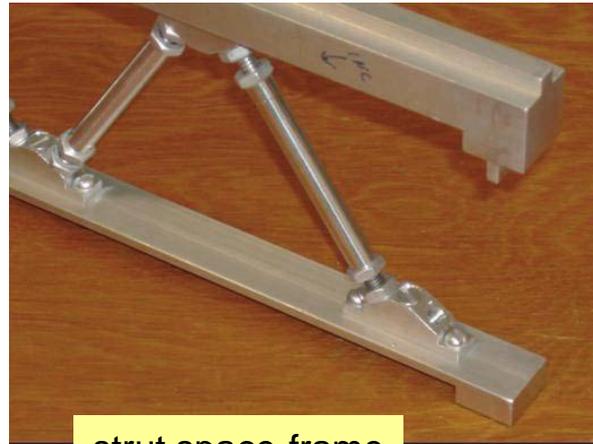
For each small test beam, there is a solid model that was used for the FEA.

Deflection of the physical prototypes was compared to the FEA.

(Carbon fiber plates are specified to have the same rigidity as the aluminum in the solid model.)



Al-C Hybrid



strut space-frame

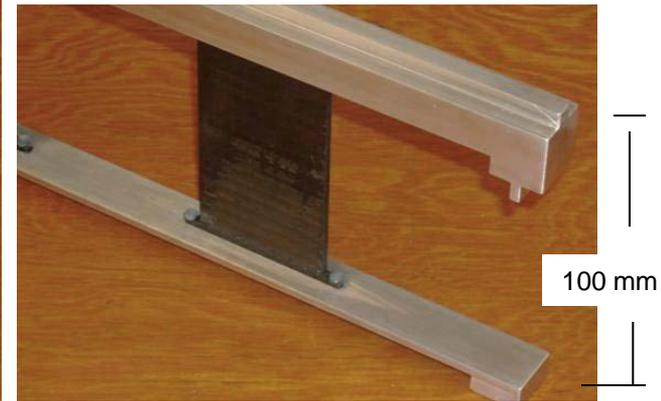
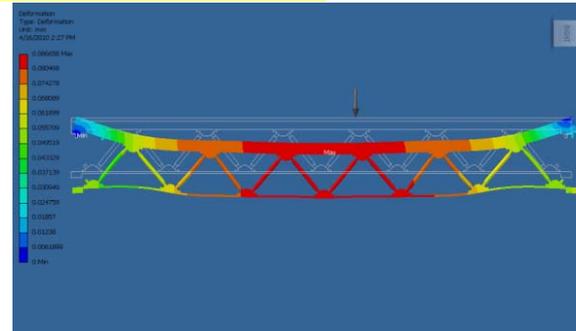
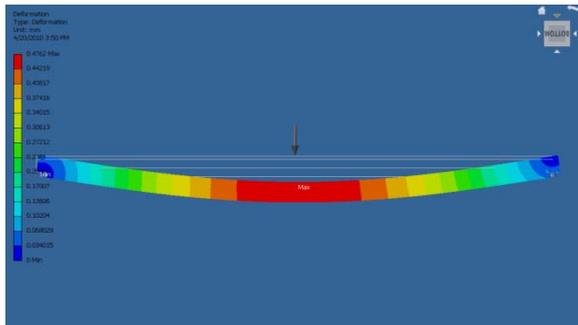


plate space-frame (carbon fiber)



Comparison of deflection for small test beams: FEA vs. measurements

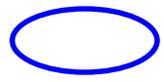
	20100408 mass	20101111 center load FEA mm/100N	20101104 center load MEASURED mm/100N	20110202 center load MEASURED mm/100N	20110316 center loaded MEASURED mm/100N
LP1	0.63 kg	0.755	0.88	0.75	0.78
Al-C hybrid (1.0 part fiber : 1 epoxy)				1.71	
Al-C hybrid (0.25 part fiber : 1 epoxy)				2.12	
LP1 (channeled) (channeled for the hybrid, but without adding carbon fiber)	0.37 kg	2.224	2.40		
space-frame (“strut”)	0.76 kg	0.111		0.11	0.12
space-frame (“equivalent-plate”)		0.111			0.14



The standard LP1 beam agrees with the FEA, except for some problems in the first measurement, probably sloppy centering the load.



The cast-in-place carbon-fiber does not come close to having the modulus of aluminum. (Possibly, with a a heat-cured epoxy, the result would have been better.)



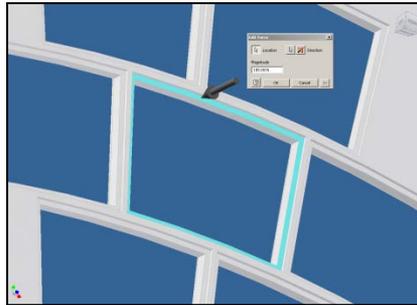
The “strut” space-frame agrees with the FEA. The model accurately predicts the strength at the joints and the design is useful for ILD.



The “equivalent-plate” space-frame is nearly equivalent to the “strut”. It was made with commercial carbon-fiber plates that were claimed to have the modulus of aluminum; possibly the modulus is ~20% low. (This could be verified.)

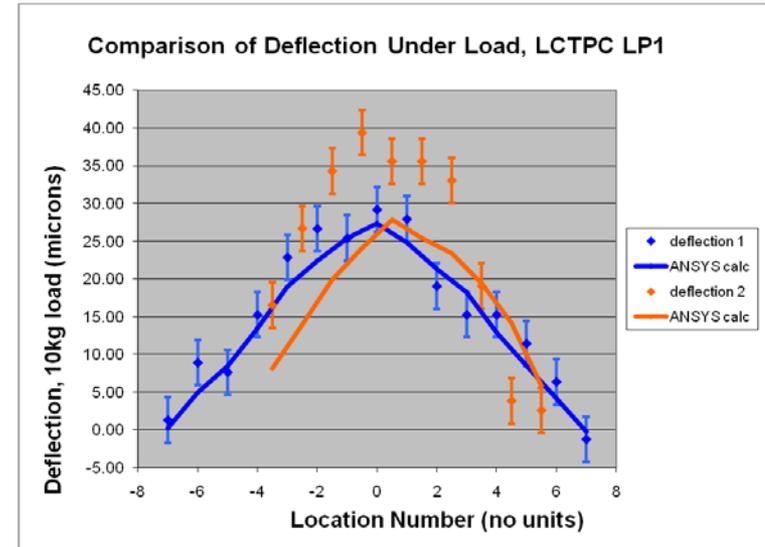
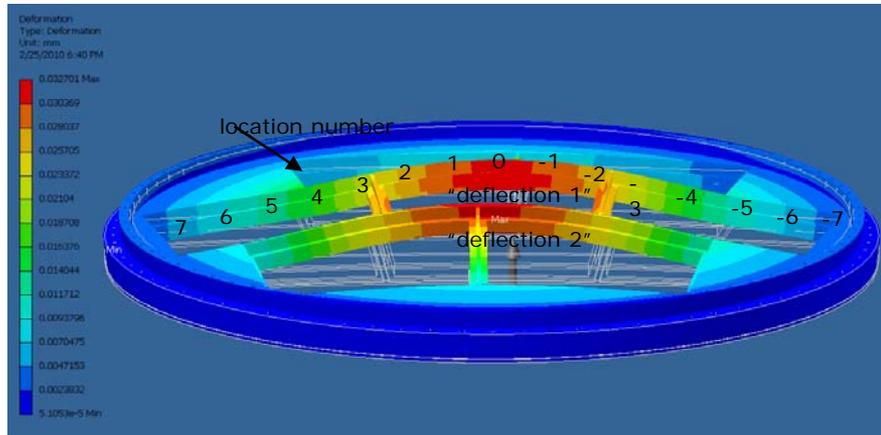
The **current LP1 endplate** was measured, providing a first validation of the FEA at the scale of the LP1/LP2 endplates.

The load of 100N (22lbs), representing 2.1 millibar overpressure, was placed “uniformly” in the center module location.

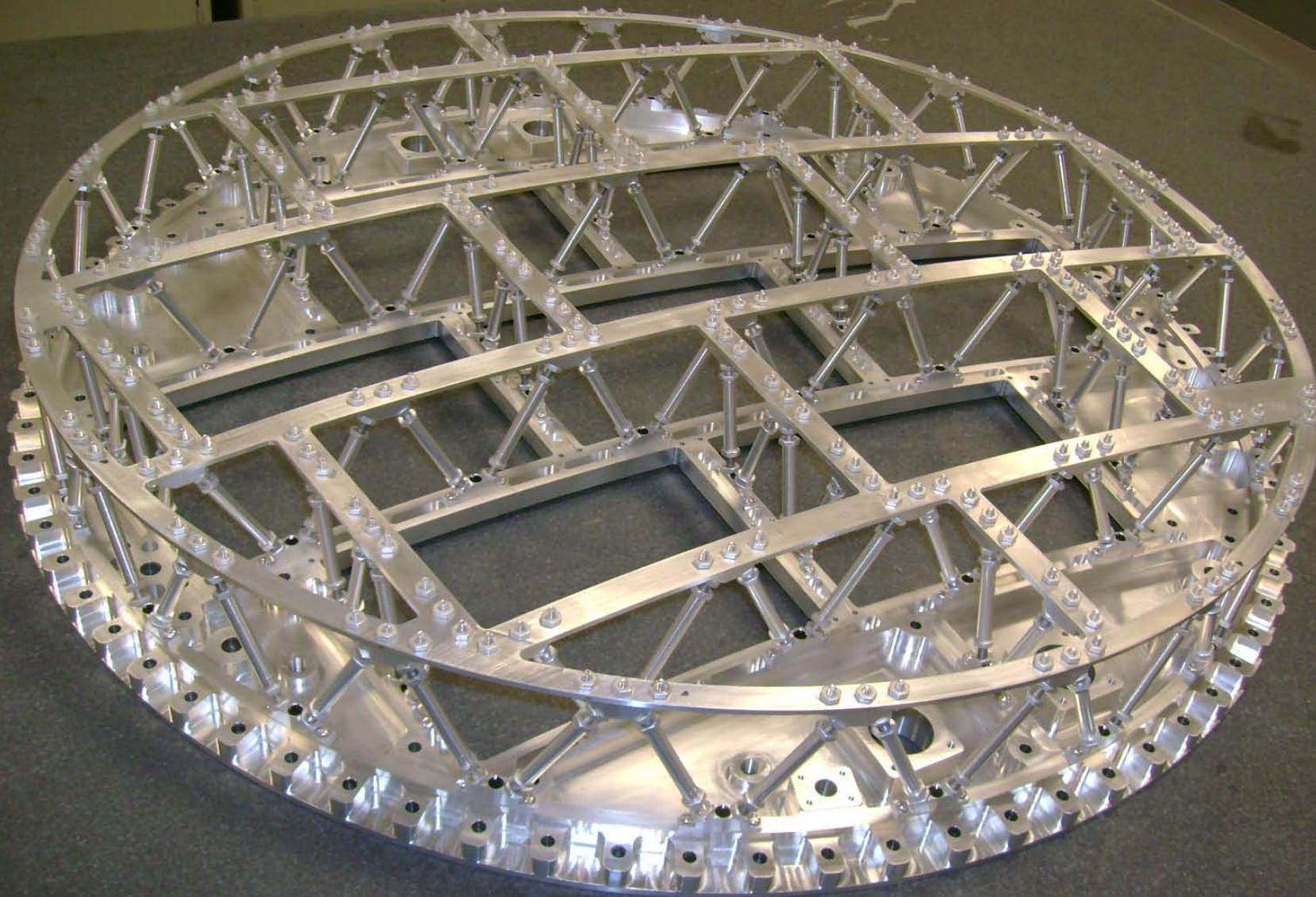


Deflection, measured across 2 lines, agrees on average.

Stress is <1% yield.



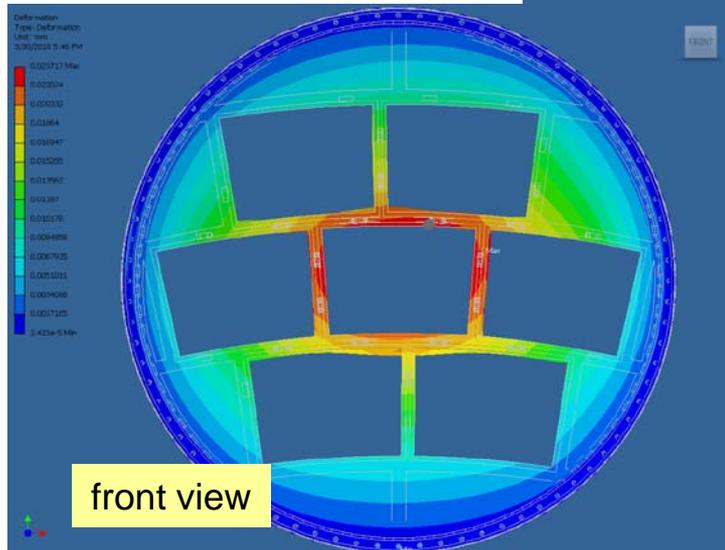
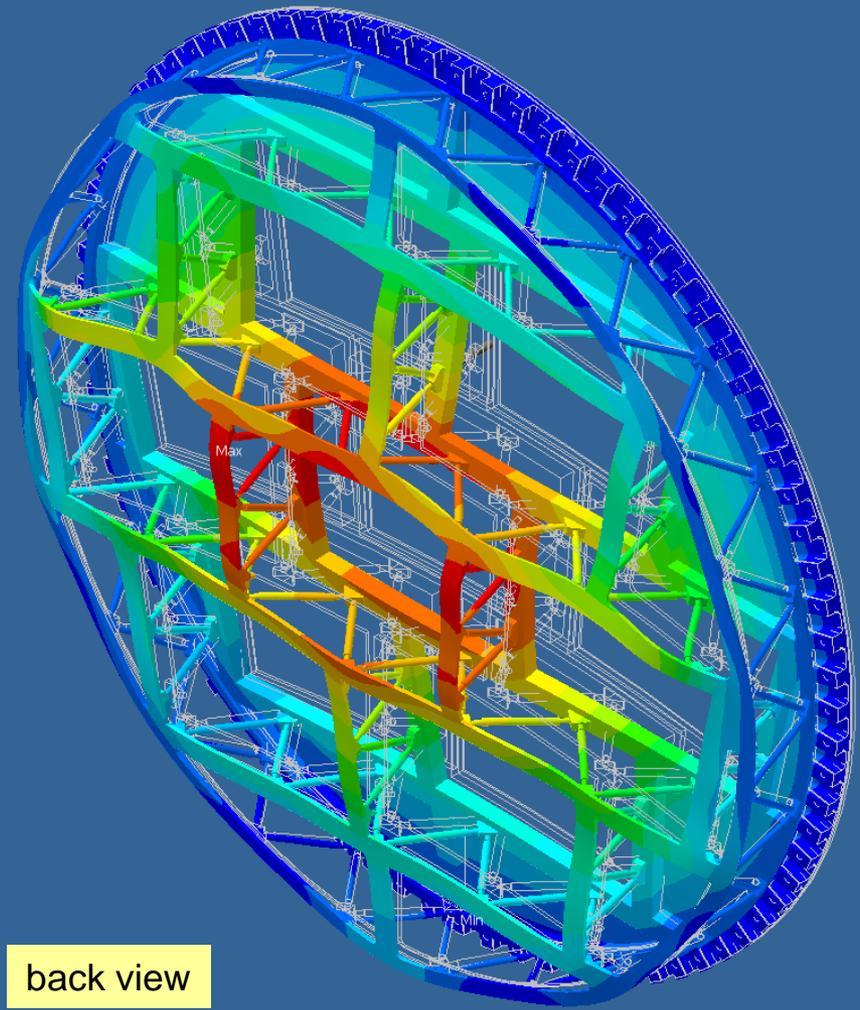
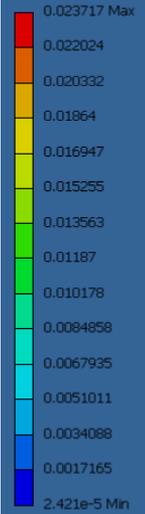
The first of two LP2 space-frame endplates is assembled (Friday, 25-March).



The FEA predicts a deflection of 23 microns / 100 N load.

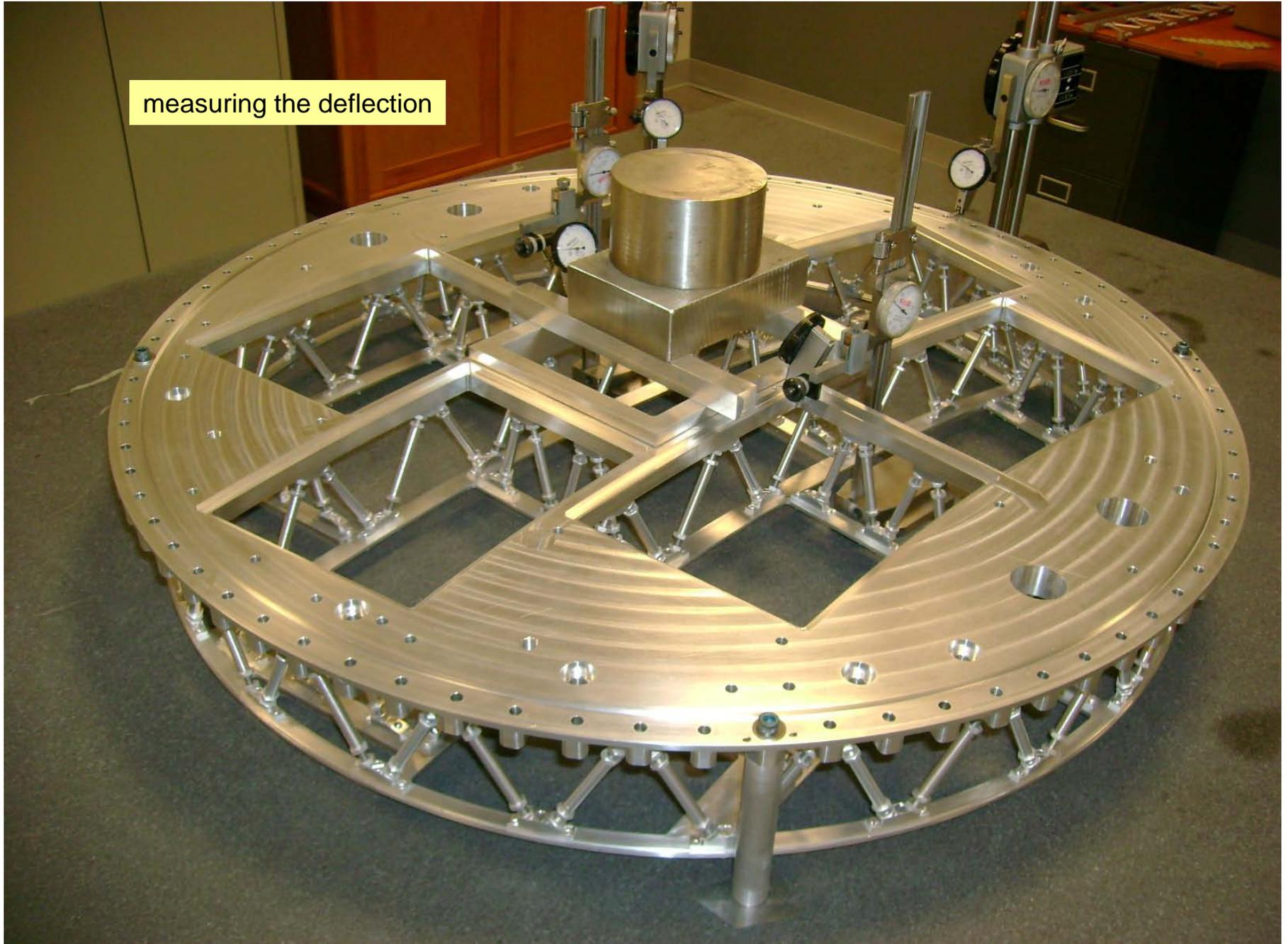
(Again, with the load applied at the center module.)

Deformation
Type: Deformation
Unit: mm
3/30/2010 5:37 PM



back view

measuring the deflection



Comparison of deflection for LP1/LP2 endplates: FEA vs. measurements

Measured mass of the LP2 space-frame endplate: 8.8kg ??? screws

Measured deflection: 27.6 microns (preliminary measurement)

a more accurate measurement requires a larger load
 height of outer rim is fixed at only 4 places,
 could use a stiffer module back-frame,
 there may be loose screws in the strut mounts

	mass kg	material %X ₀	calculated deflection microns (100 N)	stress Mpa (yield: 241)	measured deflection microns (100 N)
LP1	18.87	16.9	29	1.5	33
Lightened	8.93	8.0	68	3.2	
Al-C hybrid (channeled plus fiber)	Al 7.35 C 1.29	7.2	(68-168)	(3.2-4.8)	
Channeled	Al 7.35	6.5	168	4.8	
Space-Frame (strut or equivalent plate)	8.38	7.5	23	4.2	28

This is a fully functional replacement for LP1 endplate, shown with the lightened module back-frames.

One will be sent to DESY, where we can study system operation.

Another will be kept for measurements of long term stability and lateral strength/accuracy.

An issue:

there are difficulties installing the mounting brackets. Some minor modifications will make this easier.

A non-issue:

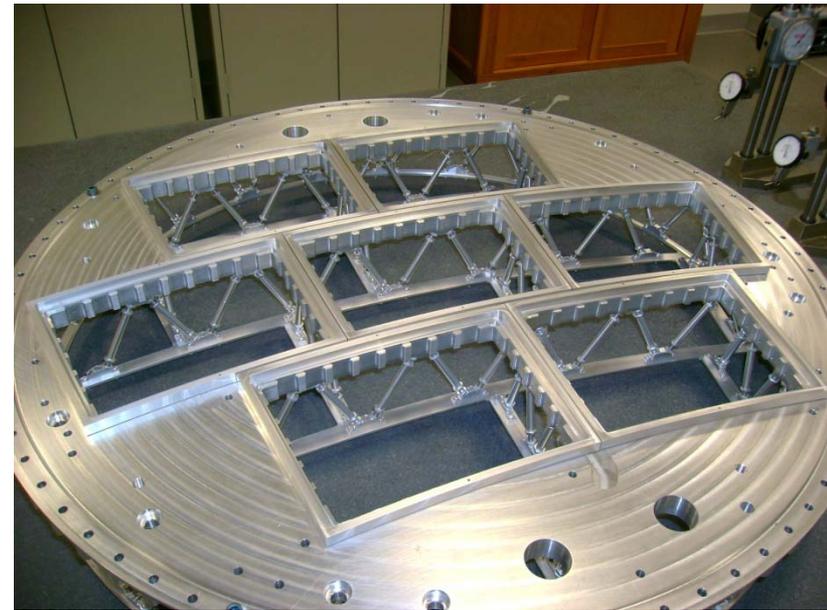
alignment of the struts is easier than anticipated.

fine and coarse thread screws,

10-32, 10-24,

metric equiv: 4.88-0.794 4.88-1.058

difference: 96 turns/inch, 0.264mm/turn



Issues related to the use of struts vs. plates.

On slide 8, I said that the ILD can be implemented with struts or equivalent plates.

Plates can be made with precision height;
adjustment is not necessary (or possible)

Plates must be glued in place.

I have chosen the strut design for the LP2 endplate because it does not require development of a procedure for gluing the 2-dimensional array.

A procedure can be developed for gluing after placement of the plates. It will require semi-automatic glue injectors which would be cost effective for the ILD scale.

Struts are adjustable at a very fine scale.

Adjustment is easier than expected.

A full iteration including height measurements and adjustment is about 2 hours.

Struts require attachment of the mounts with aluminum screws (3.35mm), which must be tightened to ~40% of the yield strength. Creep may be a problem.

One of the designs may have an advantage in the required mass in the mounting. aluminum tightness.

Issues for the construction of the ILD endplate

Machining: we are looking at a 12 foot travel milling machine.
They exist, but global tolerance is ~125 microns

Handling: inner and outer plates will require fixtures
for handling and shipping

Stress relief: requires a 12 foot square tub of liquid nitrogen (solvable).

Assembly alignment: I use a ground plate as an assembly jig.
Does not scale to ILD.
Solvable, set up stands with optical levels.

Assembly: ~3000 struts, 5 minutes each, 250 hours

Endplate alignment: not a 3000 degree of freedom exercise
only ~5 struts must be changed at any one time.

Summary

There has been modeling and FEA at several scales of ILD development:
small beams, LP1, ILD.

The space-frame design is expected to provide the required rigidity
and is a viable construction.

The FEA calculations of longitudinal deflections are validated with
small test beam and LP2 endplate measurements.

Lateral rigidity and stability: much more work is required. We are, after all,
most concerned about the affect of lateral stability on the calibration.
The new space-frame version of the LP2 endplate will be used in this study.

This ILD spaceframe design can provide

**<0.22 mm deflection (2.1 millibar overpressure)
with a contribution of 6% X_0 material (bare endplate)
and 2% X_0 from the module back-frames.**

An optimization of the design can realize >10% improvement.